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Local time dependence of Jovian radio emissions observed by Galileo

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Abstract. Galileo has been in orbit around Jupiter since December 1995. All the orbits are equatorial and elliptical, with apogees between 60 R_J - 142 R_J and perigees from 8 - 12 R_J. Since orbit injection, the plasma wave instrument (PWS) has been collecting data over specific intervals of each of the orbits at all local times and a range of different radial distances. We present the results of a survey of the data for the frequency range 300 kHz to 5.6 MHz, which includes the hectometric (HOM) and low-frequency decametric (DAM) emissions. The results indicate that both the HOM and DAM emission are more intense and occur more frequently in the midnight sector of Jupiter. This is in analogy to Earth and consistent with a magnetic substorm source for a portion of the radio emissions in this frequency range. Another peak in the power levels is observed on the Jovian dayside in the local time range 11 hrs. < LT < 12 hrs. This peak does not have a terrestrial counterpart. We speculate that this dayside peak may be a result of sampling near perigee, but we cannot rule out the possibility that this is not the case.

1.0 Introduction

It is a well-known fact that the terrestrial magnetospheric activity shows a strong dependence on solar magnetic activity. For a review of terrestrial magnetic storm phenomena, see Rostoker [1996]. Gurnett [1974] showed that auroral kilometric radiation (AKR) was correlated with discrete auroral features. Green et al. [1979], Gallagher and Gurnett [1979], and Huff et al. [1988] further showed a correlation of AKR with auroral region inverted-Vs [Frank and Ackerson, 1971], a distinctly nightside auroral phenomena.

The presence of magnetic substorms at Jupiter, however, has been the subject of investigation for some time. Krimigis and Roelof [1983], Vasyliunas [1983] and Hill et al. [1983] have all reviewed the dominance of co-rotational effects, especially in the inner magnetosphere, of Jovian magnetospheric dynamic processes. It is also well known that Jovian decametric (DAM) emissions (3 MHz < f < 40 MHz) show a high degree of order when correlated with longitude and the orbital phase of Io [cf. Carr et al., 1983]. There are some Jovian magnetospheric phenomena that indicate solar wind control.

Jovian hectometric (HOM) radio emissions are generally described as emissions in the frequency range of ~ 200 kHz to ~ 3 MHz (cf. Carr et al. [1983] and Ladreiter and Leblanc [1991]). Unlike DAM, HOM does not show any obvious Io control, but Desch and Barrow [1984] have shown the emission is correlated with solar wind velocity. More recent papers have also shown solar wind control of certain auroral emissions [Ladreiter et al., 1994; Baron et al., 1996; Satoh et al., 1996], but in general, UV auroral features show a dominant co-rotational influence [Clarke et al., 1998]. Recently, Mauk et al. [1997] have reported the presence of plasma injections observed by the Energetic Plasma Detector (EPD) on board Galileo. These injections are similar to those at Earth [e.g., Konradi, 1975] which are known to be related to magnetic substorm processes. However, a local time dependence of these plasma injections could not be determined at the time. In addition, Krupp et al. [1998] have observed energetic particle flow bursts in EPD data with about a 3-day period, which they attribute to a large-scale reconfiguration of the Jovian magnetotail. Woch et al. [1998] further analyze the quasi-periodic modulations of the EPD particle fluxes in the Jovian magnetotail. They suggest that the 3-day period indicates an internally-controlled substorm process with magnetotail reconfiguration, reconnection, and plasmoid formation. Most recently, Louarn et al. [1998] have suggested that kilometric radio emissions at Jupiter may be linked to global instabilities of the magnetosphere.

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The Galileo mission is unique in two major ways. First it is an orbiter and second it has made multiple close approaches to each of the Galilean satellites. The data from this mission can thus greatly complement and extend that of the Voyager and Ulysses flyby missions, especially the lower frequency range of DAM, a range that was not well-resolved by the Voyager Planetary Radio Astronomy instrument (PRA) due to satellite noise levels. In this paper we report on a statistical study of Jovian radio emissions which show a local time dependence of the power levels, and we relate our observations to the possibility of magnetic substorm activity at Jupiter.

2.0 Instrumentation

The plasma wave receiver on board Galileo consists of 4 different swept-frequency receivers that cover the frequency range from 5.6 Hz-5.6 MHz for electric fields and 5.6 Hz to 160 kHz for magnetic fields. We will concentrate in this study on the electric field data obtained by the high-frequency receiver, which covers the frequency range from about 100 kHz to 5.6 MHz. A single electric dipole antenna with a tip-to-tip length of 6.6 m is connected to each electric receiver. A complete set of electric field measurements is obtained every 18.67 seconds with a frequency resolution of about 10% [cf. Gurnett et al., 1992].

3.0 Observations

We have conducted a survey of the Galileo data set in the frequency range 0.3 MHz < f < 5.6 MHz for the time interval day 341, 1995 to day 91 of 1998. The study includes data from parts of 17 orbits, all local times, and a range of radial distances from about 8 R_J to over 140 R_J. All the intensity values are normalized to a distance of 100 R_J. The data have been sorted in 6° x 6° bins of Jovian satellite orbital phase versus system III longitude, λ_{III}. This bin size was chosen to produce good resolution as well as a large number of data points within each bin. The occurrence probability is determined for each bin. This is defined to be the total number of occurrences of emission above a threshold value ($10^{-17.5}$ W/m^2-Hz) relative to the total number of occurrences within each bin. Our results can be directly compared, therefore, to similar plots obtained for the Voyager 1 and 2 data [cf. Alexander et al., 1981; Carr et al., 1983].

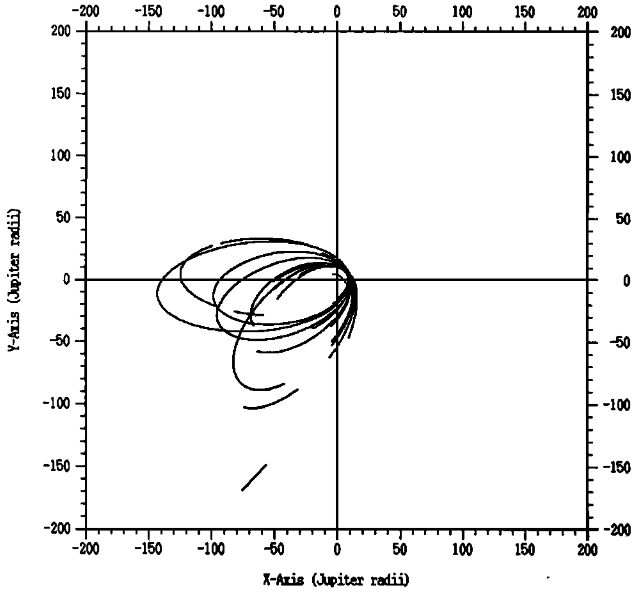

Fig. 1. This figure shows the parts of over 17 orbits where data were obtained from the plasma wave instrument on board Galileo. The segments of the trajectory are plotted in JSE coordinates in the x-y plane.

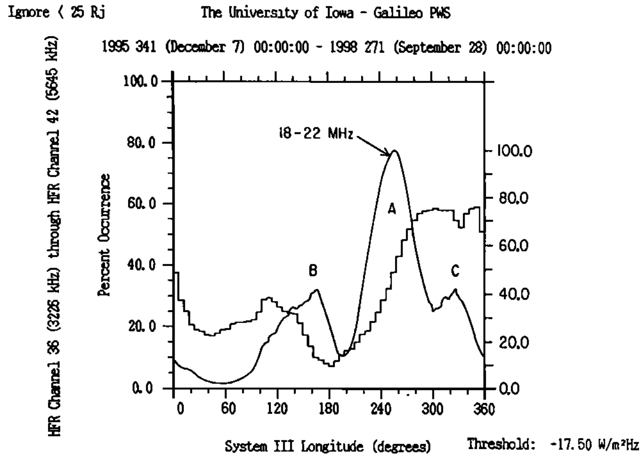

Fig. 2. A plot of percent occurrence of emission (defined in the text) versus Jovian system III longitude, showing the 3 main sources of the low-frequency DAM emission in the frequency range (3 MHz < f < 6 MHz). Also plotted are the ground-based data [cf. Carr et al., 1983] for the frequency range 18-22 MHz, with the traditional labeling of the A, B, and C sources.

In Figure 1 we show the orbit segments of the spacecraft during the time of data collection for the survey. These orbits range over a radial distance from about 9 R_J to over 140 R_J, but the line of apsides (from Jupiter to the greater apsis) of the orbits all lie within the range of local times from about midnight to about 5 hours. The magnetic latitude of Galileo varies between about -10° and +10° for the duration of the mission, i.e., the Jovicentric latitude is near 0. In Figure 2 we show the occurrence probability of the data in the low-frequency DAM range 3.2 MHz < f < 5.6 MHz versus λ_{III} or central meridian longitude (CML). Note there are 3 rather broad peaks in this plot, near 110°, 300° and 345°, with emission nulls occurring centered near 50°, 180°, and 330°. These peaks are shifted from those on the similar plot for higher frequency DAM (observations of Thieman, Ph.D. thesis, 1977, at 18, 20, and 22 MHz as reported by Carr et al., 1983, in their Figure 7.14). We have superimposed an adapted version of that figure on Figure 2. For that study the main occurrence probability of emission was centered near $\lambda_{III} \sim 255°$ for the A or main source; $\lambda_{III} \sim 155°$ for the B source; and $\lambda_{III} \sim 330°$ for the C source. The nulls of the emission at higher frequency DAM are centered near 60°, 195°, and 300°, and thus match up more closely to those observed at the lower frequencies in Figure 2. These shifts may be due to the source positions of the lower frequency DAM gyroresonant emissions occurring at larger radial positions along the magnetic field line, and thus at possibly different system III longitudes if the field line is out of the meridian plane. Also, the wave normal angle of the emission is probably dependent on frequency. Carr et al. [1983] comment that for emission below 10 MHz, the emission is more continuous as a function of CML than it is at higher frequencies, but that below about 2 MHz, HOM again displays a strong CML modulation. In Figure 3 we plot the occurrence probability versus CML for the HOM emission. Three peaks (sources) are present that are even more distinct than in Figure 2 for the DAM. The nulls are deeper, particularly near $\lambda_{III} = 340°$. The locations of the sources are shifted only slightly with respect to those measured in Figure 2 for the low-frequency DAM, with broad peaks centered near 120°, 300,° and 360° and nulls centered near 40°, 185°, and 340°. This even stronger CML dependence for the HOM emission compared to the low-frequency DAM emission of Figure 2 is in agreement with the results reported by Carr et al. [1983].

In Figure 4 we plot the power density per bin (solid curve) versus local time. The power flux is the average power within a local time bin of angular size 6°. The right-hand vertical axis displays the average radial distance of the data within each bin. This is included because of the eccentricity of the orbit. Because of the orbit (see Figure 1) most of the data in the interval from about 6 hours < LT < 20 hours are obtained near perigee, whereas the sampling at other local times occurs at much larger radial distances. Because the satellite spends much more time near apogee, there are many more data points within each sampling bin when the satellite is near apogee (thousands to tens of thousands) compared to perigee (hundreds). The spike near LT = 4.5 occurred during the orbit injection phase of the satellite, when Galileo was a large distance from Jupiter.

A most interesting feature is the increase in power levels centered in a small range of local times near noon, 11 hrs. < LT < 12 hrs.

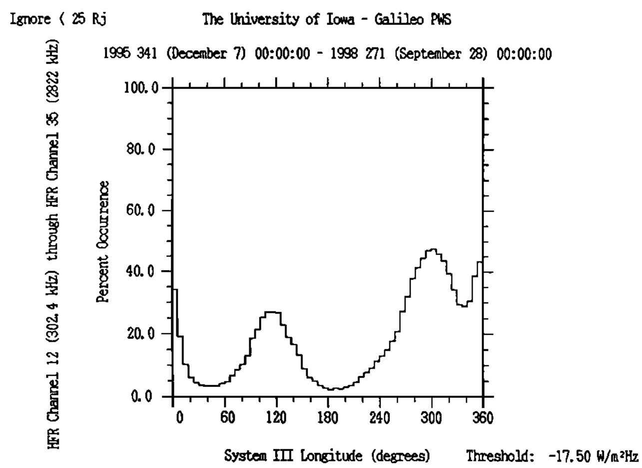

Fig. 3. A plot of percent occurrence of HOM emission (300 kHz < f < 3 MHz) versus Jovian system III longitude. The 3 main sources are more pronounced and slightly shifted compared to the low-frequency DAM emission.

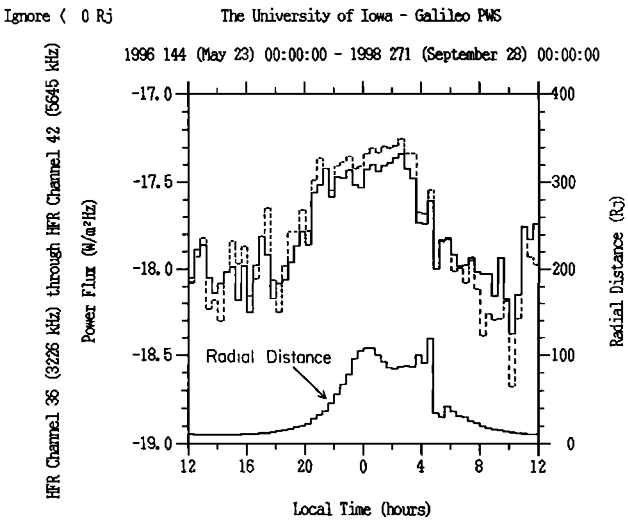

Fig. 4. A plot of the average power per bin (6°) versus local time (solid top curve) for the low-frequency DAM emission. The dashed curve is the same except it is limited to the magnetic latitude range -5° < MLAT < 5°. Increased wave power levels in the range of local times from about 20 hrs. to about 4 hrs. are evident. There is also an interesting increase in power levels in the narrow range 11 hrs. < LT < 12 hrs. The lower curve is a plot of the average radial distance of the satellite for data taken within each 6-degree bin.

This peak occurs near, but not at, perigee for each of the orbits. In the range 12 hrs. < LT < 20 hrs., there are smaller peaks in the power levels. One must consider the shadowing effect of the Io torus when the spacecraft is within about 20 R_J. This effect is clearly observed by Galileo as on Voyager and Ulysses [cf. Ladreiter et al., 1990; Carr et al., 1983], but refractive effects decrease rapidly for f > 800 kHz, which is well below the minimum frequency of our survey of DAM emission.

The latitudinal beaming of HOM emission has been studied by many authors [cf. Alexander et al., 1979; Ladreiter and Leblanc, 1990]. Ladreiter and Leblanc [1991] have shown via ray tracing how the HOM emission is focused by the Io torus. We have investigated the effects of this latitudinal beaming on our local time power measurements of the low-frequency DAM by repeating our study of the power flux but restricting the sampling to magnetic latitudes in the range of -5° < MLAT < 5°. These results are also shown in Figure 4 (dashed curve). The power flux for this sorting is seen to be somewhat higher than the solid curve on the nightside centered near midnight at large radial distances in the local time range between about 18 hrs. and 5 hrs. The dashed curve is generally lower than the solid curve at smaller radial distances in the dayside local time range from about 6 hrs. to 12 hrs. Nevertheless, the two curves (broad and restricted latitudinal extent) are qualitatively very similar.

In Figure 5 we show the power density for the HOM frequency range 0.3 MHz < f < 3.0 MHz. The results are qualitatively similar to those for the DAM frequency range. The power levels of HOM are somewhat smaller than for the low-frequency DAM in the range of local times from 20 hrs. to about 4 hrs. In the case of the HOM emission, however, some power levels will be reduced due to the Io torus shadowing mentioned above, which takes place for r ≤ 20 R_J. Nevertheless, it is clear from Figure 5 that the power levels start to decrease away from the midnight sector well outside a radial distance of 20 R_J. The peak in power levels in the range 11hrs. < LT < 12hrs. is even larger for the HOM than for the DAM. Again, for 12hrs. < LT < 20 hrs. the power levels show minor peaks.

As in the case of the low-frequency DAM emission, we have repeated the study of power flux of the HOM emission using a restricted range of magnetic latitudes (- 5° < MLAT < 5°). The results are plotted as a dashed curve in Figure 5 and the results are similar but somewhat enhanced compared to the case of the low-frequency DAM. In Figure 5 we see the emission for the latitudinally confined HOM emission is enhanced relative to the solid curve on the nightside centered near midnight at large radial distances in the local time range between about 18 hrs. and 6 hrs. The dashed curve is generally lower than the solid curve at smaller radial distances in the dayside local time range from about 6 hrs. to 14 hrs. Again, however, the two curves (solid and dashed) are qualitatively very similar.

4.0 Summary and Conclusions

The Galileo spacecraft is the first orbiting man-made satellite of Jupiter, and consequently provides a unique data set. For the first time the Jovian magnetosphere is being mapped in a systematic way. This paper reports the results of a survey of the plasma wave data for a period of time extending from day 341 of 1995 until day 314 of 1997, thus covering parts of 17 orbits and all local times. Because of the eccentricity of the orbits, the sample ranges over radial distances from about 9 R_J to over 140 R_J. The magnetic latitudes range from about -10° to +10°.

The results of our survey indicate that the low-frequency DAM and HOM radio emission power levels are higher by a significant value when Galileo is in the local time range from about 20 hrs. to about 4 hrs. This is consistent with an active wave power generation region on the nightside of the Jovian magnetosphere, similar to the Earth's auroral kilometric radiation (AKR) source region [cf. Kurth et al., 1975; Gallagher and Gurnett, 1979]. For the Earth, the generation of AKR is known to be associated with auroral activity and inverted-V particle precipitation and acceleration regions often observed in the terrestrial nightside auroral regions [cf. Green et al., 1979; Gurnett and Inan, 1988]. Maps of average fluxes of precipitating electrons and ions for the Earth polar cap regions clearly show enhancements in the midnight sectors [cf. Hultqvist, 1973; Liou et al., 1997]. This phenomena is typically explained as due to a magnetic substorm process [Akasofu, 1968]. In the case of

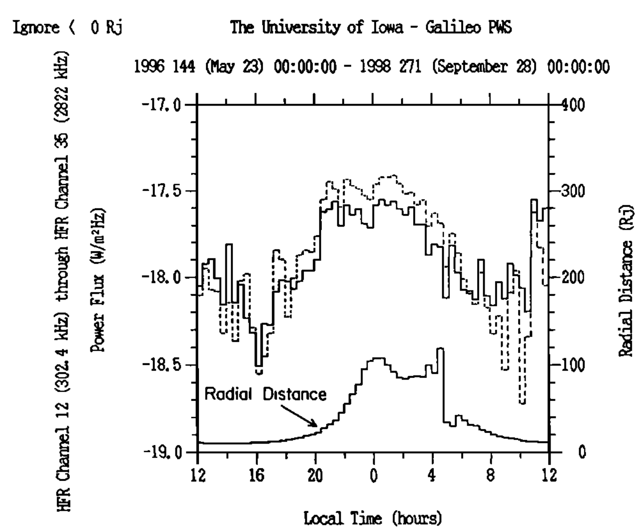

Fig. 5. A plot of the average power per bin (6°) versus local time (solid top curve) for the HOM emission. The dashed curve is the same except it is limited to the magnetic latitude range -5° < MLAT < 5°. Increased power levels are again seen in the range of local times from about 20 hrs. to about 4 hrs. and 11 hrs. < LT < 12 hrs.

Jupiter, this effect, therefore, may be interpreted as suggestive of the presence of magnetic substorms. Such an interpretation is not inconsistent, for instance, with the results of Louarn et al. [1998] and Jovian kilometric radio emissions or the results of Mauk et al. [1997] regarding injection events observed by the Energetic Particle Detector (EPD) on board Galileo. These latter authors interpreted their results as reminiscent of observations made at Earth by geosynchronous satellites and understood as due to plasma injection events of magnetic substorms. Over a hundred such individual events have been identified to date. As reported by Mauk et al. [1997], however, it is generally not possible to determine the local time of each injection, because the corotational drift time and time of injection provide a rather large degree of uncertainty. A direct comparison of Galileo PWS data with particle data obtained by EPD for time periods of energetic particle bursts [cf. Figure 4 of Krupp et al., 1998] has shown an excellent agreement. This agreement is the subject of an ongoing study. The combination of the radio emission power levels observed by PWS and the observations of plasma injection events, energetic particle bursts, and quasiperiodic particle modulations observed by EPD lend support to the hypothesis of magnetic substorms at Jupiter.

Another interesting result is a peak in radio power levels centered in local time 11hrs. < LT < 12hrs. This peak does not have a counterpart at Earth in the AKR power distributions [cf. Figure 4 of Gallagher and Gurnett, 1979]. This power density peak may be related to the influence of the Io torus, which is a source not only of radio emission, but also of refraction and scattering of emission. The dayside peak in power is not centered on perigee of the orbits, however, which is near about 14 hrs. It is thus not entirely consistent with only a torus or radial distance effect. We can not rule out the possibility that Jupiter has a dayside source of radio power, unique from the Earth, and at this time not completely understood.

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